Evaluation of a Geometric Dimensioning and Tolerancing Course for Engineering Technology Students

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Abstract

During the Fall 2016 semester a geometric dimensioning and tolerancing course was offered for the first time at Illinois State University. The course learning outcomes included symbol identification, identifying features with and without size, specifying GD&T within given design scenarios, calculating virtual condition, determining advantages for different material condition modifiers, applying datum reference frames to designs, and demonstrating proper inspection set-ups and procedures for verifying geometric tolerances. This digest outlines the main topics and structure of the course, summarizes some of the assessment data gathered during the semester, and analyzes student performance on concepts presented in the pretest.

Introduction

Geometric dimensioning and tolerancing (GD&T) is an unambiguous mathematical language that describes form, orientation, and location of part features within specified zones of tolerance (Neumann & Neumann, 2009). Although the standards for dimensioning and tolerancing (ASME, 2009) were developed many years ago, GD&T has not been a topic widely integrated into engineering programs. One reason for not including it in curricula is related to its importance relative to other topics. In addition, some of the misconceptions of GD&T also contribute to its lack of presence in curricula (Krulikowski, 2003). When individuals are not prepared to apply GD&T correctly, several things can happen (Tandler, 2010). These include:

- Parts appear to assemble and operate correctly, but in practice they fail in all aspects.
- Burden is placed on machinists by supplying them with bad information – and then placing blame on them when things do not work.
- The costs of parts increase.
- Incorrect specifications are placed on drawings, which force metrologists to interpret the correct meanings.
- Time and money are wasted, blame is placed on GD&T, when the real problem is misuse.

More recently we have seen an increase in GD&T publications related to engineering education and product definition (Paige & Fu, 2017; Yip-Hoi & Gill, 2017; Waldorf & Georgeou, 2016; Witherell, Herron, & Ameta, 2016; Hewerdine, Leake, & Bell, 2011). These articles make an effort to reduce some of the misconceptions involved with GD&T.

Rationale for the Course

Several things contributed to justifying a single course in GD&T at Illinois State University. Since the main program objective is to prepare professionals who can integrate engineering principles with modern manufacturing technologies, it seemed natural that GD&T concepts would be discussed at some level. The program advisory board confirmed the importance of adding this course in 2015, and the course was offered for the first time in the fall of 2016. Specific course objectives were outlined, and these were tied back to program level outcomes to satisfy accreditation standards. The Association for Technology, Management, and Applied Engineering has established standards for program excellence, and Standard 4 addresses program competency identification and validation:

> Measurable competencies shall be identified, assessed and validated for each program/option. These competencies must closely relate to the general outcomes established for the program/option and validation shall be accomplished through a combination of external experts, an industrial advisory committee and, after the program is in operation, follow up studies of program graduates (ATMAE, 2017).

The Engineering Technology Program at Illinois State University has six program outcomes. These outcomes are listed below. Activities in TEC333 address the last two program outcomes.

1. Interpret and apply basic concepts of materials science such as strength of materials, structural properties, conductivity, and mechanical properties. Perform various non-destructive and destructive materials testing procedures.
2. Analyze and apply basic electricity and electronic principles within the various manufacturing environments and applications such as industrial robots, controls, and other such systems.
3. Monitor and control manufacturing processes or other industrial systems.
4. Select appropriate manufacturing processes for product production applications such as forming, molding, separating, conditioning, joining, and finishing.
5. *Utilize 2-D and 3-D computer-aided design systems to create drawings and models for products, machines, jigs, fixtures, and other mechanical devices used in manufacturing environments.*
6. *Read and interpret manufacturing documentation such as blue prints, technical drawings and diagrams, production plans, tooling plans, quality plans, and safety plans.*

TEC333 also has specific course objectives. Upon successful completion of the course, students will be able to:

1. Identify geometric characteristic symbols and the other symbols associated with geometric dimensioning and tolerancing.
2. Identify features with size and features without size.
3. Specify limit dimensions.

4. Calculate virtual condition for features.
5. Determine the advantage of using different material condition modifiers.
6. Apply appropriate datum reference frames to designs.
7. Apply appropriate form, orientation, profile, runout, and location tolerances to designs.
8. Execute proper inspection set-ups and procedures for checking geometric tolerances.

Outline of Course

TEC333 is designed to provide students an overview of the basic terminology used in GD&T, opportunities to apply GD&T in a design setting for modestly complex parts, activities where students apply GD&T within a CAD environment, and laboratories where students inspect parts using calipers and coordinate measuring machines (CMM). To accomplish the course objectives, students complete a combination of workbook activities, CAD applications, caliper measuring activities, and coordinate measuring machine inspection activities. The main source for the content knowledge in the course is *GeoTol Pro: A Practical Guide to Geometric Tolerancing per ASME Y14.5 – 2009* (Neumann & Neumann, 2009). This is a workbook style text that contains end-of-unit exercises geared toward industry professionals. Rather than collect workbooks each period, exercises are discussed in class and online quizzes of unit material are administered through the university's learning management system. In addition to the online quizzes, students GD&T knowledge is assessed through two tests and a final exam. The weekly topics are shown in Table 1.

Assessment of Student Knowledge

Students' entry level knowledge of GD&T was assessed during the first day of class with a pretest. The topics included in the pretest covered a broad range of material in the course, but it was not intended to cover some of the course objectives associated with more applied materials. The pretest included items related to: identifying current standards related to dimensioning and tolerancing; given a drawing, label symbols (all around, countersink, datum feature, basic dimension, etc.); given a drawing, label the dimensions referring to a feature with size; given a drawing: identify the MMC of a specified hole, the amount of tolerance allowed if a boss/hole is produced at a certain size, and label the datum reference frame origin; given a drawing with a profile tolerance applied, identify the type of the profile tolerance (bilateral-equal, bilateral-unequal, unilateral-in, and unilateral-out); given a drawing, sketch datum feature symbols per descriptions; given a drawing with position tolerances, calculate virtual sizes; given a sentence description of a composite position tolerance, sketch the feature control frame; and given a nominal size, specified fit (e.g., RC2), and a fit table, write out the limit dimension for a hole and pin system.

Table 1. Outline of TEC333.

Week	Topic	Assignment
1	Orientation / Safety discussion	
	Introduction to GD&T	**Quiz 1**
2	Limit Dimensioning / Limits of Size	**Quiz 2**
	Lab Activity	**LAB 1** – Measuring with calipers
3	How the GD&T System Works	**Quiz 3**
4	NX Modeling	Review of NX commands.
	Lab Activity	**LAB 2** – CMM Lab **LAB 3** – NX model & drawing
5	Position Tolerance Verification	**Quiz 4** **LAB 4** – Excel table for pos. ver.
	Lab Activity	**LAB 5** – CMM Lab **LAB 6** – NX model & drawing
6	Production Plans and Virtual Condition	**Quiz 5**
	TEST #1	Review Readings
7	The Datum Reference Frame	**Quiz 6**
	Lab Activity	**LAB 7** – CMM Lab **LAB 8** – Functional Gage Activity
8	**Lab Activity**	Continue Working on Labs
	Form Tolerances	**Quiz 7**
9	Orientation Tolerances	**Quiz 8**
	Profile Tolerances	**Quiz 9**
10	**Lab Activity**	**LAB 9** – CMM Lab, Checking Profile **LAB 10** – NX Lab
	Datum Feature Modifiers	**Quiz 10**
11	**TEST #2**	Review Readings
	Catch up day – ATMAE Conference	Work on assignments
12	The Datum Reference Frame II – Targets Irregular Surfaces	**Quiz 11**
	Lab Activity	**LAB 11** – Casting Drawing
13	The Datum Reference Frame III – Advanced Concepts	**Quiz 12**
	Lab Activity	**LAB 12** – Pattern of Holes as a Datum
14	Position Tolerances	**Quiz 13**
	Lab Activity	**LAB 13** – CMM Lab, Checking Position
15	Coaxial Controls	**Quiz 14**
	Fastener Formulas and Screw Threads	
16	**Final Exam**	Review Readings

Table 2 maps the pretest items to other assessments in the course. Each assessment column displays the number of correct responses to that item. For example, pretest question 1 asked students to identify the current U.S. Standard for Dimensioning and Tolerancing. Only one student responded correctly. The question was also asked on the first test and on one of the online quizzes. One student missed that question on the first test, but all 12 students answered correctly on the online quiz. Blank cells indicate the pretest item was not assessed on that particular test, quiz or exam. Figure 1 shows an example item from the pretest.

Table 2. Number of Correct Responses to Assessment Items.

Pretest Item	Summary of question	Pretest	Test 1	Test 2	Quiz	Exam
1	Identify current ASME Standard	1	11		12	
2	Identify all around symbol	1	12		12	
3	Identify countersink symbol	12	12		12	
4	Identify datum feature symbol	6	10		12	
5	Identify depth symbol	11	12		12	
6	Identify feature control frame	12	12		12	
7	Identify basic dimension	9	12		12	
8	Identifying features with size	0	4		10	
9	Calculating MMC of a boss/hole	7	11		12	
10	Position tolerance RFS	0	7		12	
11	Tolerance on a bolt circle - basic	2	7		4	
12	Position tolerance with MMC	0	10		10	10
13	Label DRF origin	0	8			
14	Identify unilateral in profile tolerance	3		10		
15	Sketch DFS on surface A	5		10	12	11
16	Sketch DFS large hole	4		11		
17	Sketch DFS center plane	0		10		
18	Sketch DFS pattern of holes	5		12		
19	Virtual size of a hole	1	6		10	
20	Virtual size of a cylinder	1	9		10	
21	Recognize 2 holes/cylinders as a datum	1		12	11	
22	Recognize center plane as datum	0		10	9	12
23	Recognize hole as datum	3		5	5	5
24	Correctly sketch FCF from description	0	10			
25	Look up limit dimension from fit table	1	6		11	8

On the drawing below, calculate the virtual sizes for the identified features.

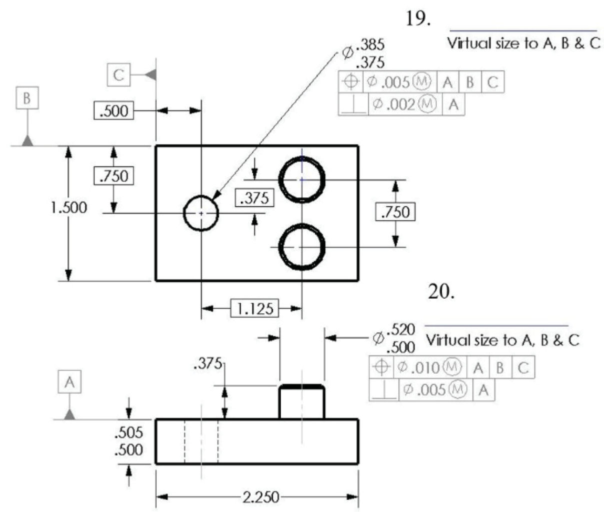

Figure 1. Example Item from Pretest.

Results

The data in Table 2 give a good indication of the topics students did and did not know at the beginning of the course. All students could identify the symbols for countersink and depth on the pretest, and all but one student correctly identified the feature control frame. Most students could recognize a basic dimension on the pretest. Seven of the pretest items were missed by all students, and six items were missed by all but one of the students.

The data also indicate how students progressed throughout the course on items assessed on the pretest. In general, it appears that students learned most of the concepts that were covered in the pretest since later assessments indicate higher levels of achievement. There are a few exceptions. These include recognizing that basic dimensions do not have a tolerance, recognizing holes as datums on a drawing, and correctly looking up limit dimensions on fit tables.

In addition to these data, an end-of-course evaluation and an end-of-course survey were administered to students. Both gave students an opportunity to give written comments about the course. The most consistent comment given by students was increasing the time spent on the two coordinate measuring machines. Five of the 12 students also indicated that they really liked the workbook style textbook for the course.

Conclusions and Recommendations

This digest only attempted to examine students' performance on pretest items in the course and then analyze how they performed on similar items later in the course. With the exception of completely understanding basic dimensions, recognizing hole features as datums, and correctly interpreting fit tables, most students mastered the concepts presented on the pretest later in the course. The data revealed areas where additional practice exercises may be useful. These include identifying features with size, identifying when overall drawing tolerances apply to dimensions, determining where the datum reference frame origin is on a design based on the datums, calculating virtual condition, recognizing datums that are based on holes, and correctly looking up limit dimensions from fit tables.

Future work will involve examining whether overall objectives for the course were met based on student performance on tests, quizzes, exams, and labs. In addition, data from the fall 2017 semester will be analyzed to determine if student performance is consistent with the fall 2016 semester.

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